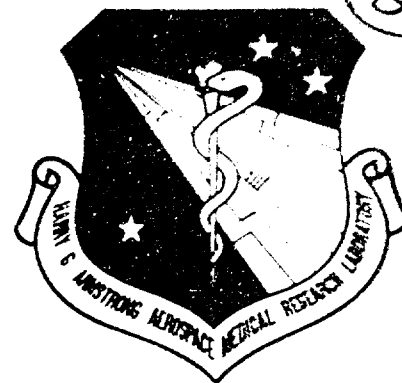AAMRL-TR-89-044 **AD-A216 953**

A NEW METHOD FOR MEASURING THE TRANSMISSIVITY OF AIRCRAFT TRANSPARENCIES (U)

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FINAL REPORT FOR OCTOBER 1988 - SEPTEMBER 1989

NOTICES

TECHNICAL REVIEW AND APPROVAL

AAMRL-TR-89-044

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

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The transmissivity of aircraft transparencies is currently measured following the American Standard for Testing and Materials Test Method D-1003. This method, originally intended for the measurement of small, thin, flat parts, has several shortcomings for measuring aircraft transparencies. A new method for measuring transmissivity, which overcomes the shortcomings of D-1003, is described. The precision of both methods was determined in laboratory tests; the results of these tests are presented. The new test method, in addition to its application advantages, is slightly more precise than ASTM D-1003.

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Summary

Transmissivity is a measurement of the relative amount of light transmitted through a part. It is an important optical parameter for aircraft transparencies, since it determines the apparent brightness of the objects observed outside the cockpit. Because visual parameters such as acuity, contrast threshold, and color perception vary with brightness at low luminance values, transmissivity can have a direct effect on vision.

The method currently used throughout the aircraft transparency industry to measure transmissivity is the American Standard for Testing and Materials Test Method D 1003. This method was originally developed for applications involving small, thin, flat transparent parts, and was later adopted by members of the aircraft transparency community. However, D 1003 has several shortcomings for measuring aircraft transparencies, including its limitation to small, thin, flat parts, the inclusion of scattered light in determination of the transmissivity value, the restriction to making measurements perpendicular to the sample surface, and the inability to measure transparencies already installed on an aircraft. Because of these shortcomings, a new method for determining transmissivity was developed which overcomes the deficiencies of D 1003. This new method, which uses a hand-held photometer, a light source, and a black reference, is described in detail. The precision of both the new method and the D 1003 method were determined through laboratory testing; the results of these tests are presented. Besides overcoming the above limitations of D 1003, the new method is also slightly more precise.

Preface

This report was prepared under work unit 7184-18-02 by members of the Crew Systems Effectiveness Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Funding was provided by the Wright Research and Development Center's Aircrew Protection Branch (WRDC/FIVR).

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Introduction

1.1 Background

The transmissivity, t, (also called the transmission coefficient) of a transparency is a measurement of the relative amount of light transmitted through the part. It may be defined as the ratio of the luminance of an object measured through the part to the luminance of the object measured directly. For example, a typical pair of sunglasses has a transmissivity of about 0.10, which means objects appear 10% as bright looking through the sunglasses as they would if they were viewed without the sunglasses. A pair of clear eyeglasses has a transmissivity of about 0.97, and an untinted automobile windshield has a transmissivity of about 0.90.

For a person viewing an object through a transparency, the observed luminance depends on both the luminance of the object and the transmissivity of the transparency. Since many visual parameters depend upon luminance (brightness), transmissivity can have a noticeable effect on vision.[6] As a general rule, acuity, contrast threshold, and color perception decrease with low luminance. A lower transmissivity, however, does not decrease the contrast of objects viewed through the transparency, only their apparent brightness.

The transmissivity of an aircraft transparency, which ranges from about 0.20 – 0.90 when measured at the pilot's viewing angle, is usually not a concern for daylight flying. When the luminance of the external scene is high, as it is for most daylight flying conditions, a low transmissivity of about 20% is acceptable, because the observed scene is still so bright that visual performance is not degraded. In fact, during bright daylight flying, pilots often lower the brightness of the external scene by using their sun visor, which is about 12% transmissive, without degrading their vision. A low transmissivity of an aircraft windscreen generally becomes a concern during two notable occasions: flying during low ambient light conditions (nighttime, dusk, heavy overcast) and/or flying when viewing through a multiple element optical system.

Flying while viewing through a multiple element optical system is a common occurrence in military aircraft. Often the pilot views not only through the windscreen, but also through a head-up display (HUD), a visor, and perhaps even his glasses. Thus the light from the external scene may be transmitted through as many as four optical media, each of which has its own transmissivity. Since transmissivity is a multiplicative parameter, the amount of light reaching the pilot's eyes depends upon the product of the transmissivities of all the optical media through which it passes. For example, if the pilot is wearing a clear visor ($t = 0.92$), has a conventional HUD combiner ($t = 0.50$), and is viewing straight ahead through an F-16 solar coated windscreen ($t = 0.65$), then the total transmissivity would be:

$$t = 0.92 \times 0.50 \times 0.65 = 0.30 \qquad (1.1)$$

Thus only 30% of the incident light reaches the pilot. This reduction in luminance is not significant during daylight conditions. However, during dusk, dawn, or heavily overcast conditions, this will tend to reduce the pilot's visual acuity by a small amount. Because the transparency must be designed for all flight conditions, including nighttime, it is desirable that the transmissivity be kept as high as possible.

1.2 Purpose

The transmissivity of aircraft transparencies is currently measured using the American Society for Testing and Materials Test Method D 1003-61. This method, which uses an integrating sphere approach (see figure 1.2), has received wide acceptance as the way to measure luminous transmissivity of transparent materials. Originally intended to measure small, thin, flat, transparent samples, this method has also been used for other applications. However, D 1003 has serious shortcomings for measuring aircraft transparencies.

First, the test method requires critical alignment of equipment on both sides of the transparency. This makes it difficult or impossible to measure parts that are already installed on an aircraft, since the transparency cannot be moved to align the optical system.

Secondly, many aircraft transparencies are large, thick, curved parts, instead of small, thin, flat parts for which the test was designed. These larger parts cannot be properly placed in the test apparatus such that the entrance aperture of the integrating sphere can capture enough of the scattered light for an accurate measurement.

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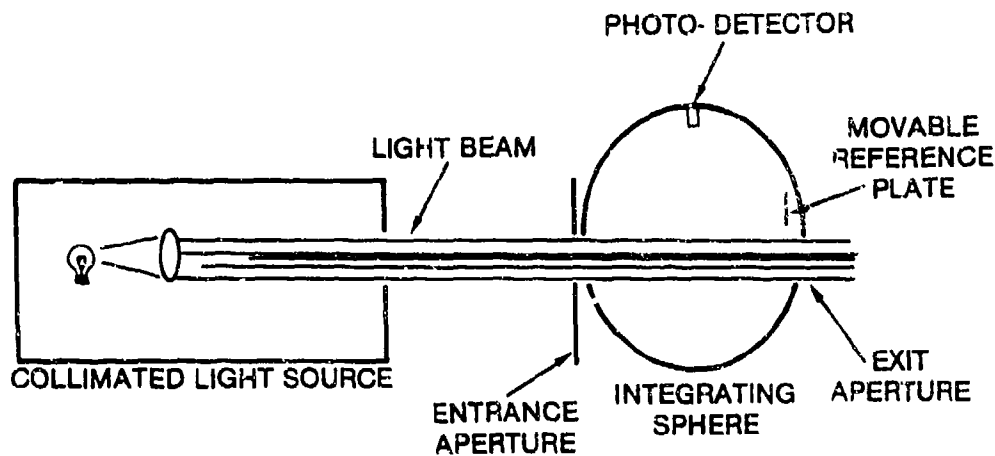
Figure 1.1: Test apparatus for ASTM D 1003.

Thirdly, this test method is restricted to measuring the luminous transmissivity of the material in a direction perpendicular to its surface. For the majority of aircraft windscreens, the pilot does not view through the transparency perpendicular to the surface. Since the transmissivity varies as a function of viewing angle, the values of transmissivity measured perpendicular to the surface do not indicate what the pilot sees when viewing through the windscreen.

Finally, the integrating sphere method does not distinguish between scattered and image-forming light. In the D 1003 method, both the scattered and image-forming light contribute to the transmissivity value. However, only the image forming light is useful; the scattered light has a negative impact on external viewing and should not be considered in calculating the transmissivity.

To illustrate this concept, consider a piece of frosted glass which transmits 50% of incident light and a sunglass lens which transmits 10% of incident light. Even though the frosted glass has a higher transmissivity than the sunglasses, the sunglasses provide a clear image, whereas the frosted glass provides no image whatsoever. Thus the absolute transmissivity is not always a good measure of the quality of a transparency.

For the above reasons a new test procedure, described in the following sections, has been developed to measure the transmissivity of a transparent part at any angle without critical

alignment of the equipment items on either side of the transparency. This procedure can also be used on large, thick, or curved parts, and on parts that are already installed.

Method

2.1 Terminology

Transmissivity The ratio of the luminance of an object measured through the medium to the luminance of the object measured directly.

Photopic curve The spectral sensitivity of the eye for daytime conditions as defined by the Committee Internationale d'Elairage (CIE) 1931 standard observer.

Photometer A device that measures luminance as defined by the spectral sensitivity of the photopic curve.

Transmission coefficient Same as transmissivity.

2.2 Apparatus

Test Environment It is preferable to carry out this test procedure in a light controlled environment although this is not absolutely necessary. The transparency should be shaded from direct sunlight falling on the surface and a light-absorbing, black cloth should be placed in the appropriate geometry with respect to the transparency to reduce reflections (see figure 2.1).

Photometer Any properly calibrated photometer may be used for this measurement. It must have a measurement field that is smaller than the regulated light source to insure accurate readings. It is recommended that a small, portable photometer with a one (1) degree field of view or smaller be used.

Light Source The light source must be regulated to insure that it does not change luminance during the reading period. It should have a relatively large, diffusely emitting surface area to permit easy measurement when using the photometer. The spectral

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distribution of the light source is not critical unless the transparency under test has significant spectral peaks or voids. If the test transparency is colored or has a spectral transmissivity containing peaks or voids in the visible range, then the light source should be specified. (A National Institute of Standards and Technology standard light source is recommended.)

For daylight measurements it is possible to use a white reflecting surface illuminated by sunlight instead of a powered light source. Care must be taken that the luminance of the reflective surface does not change during the reading.

Black Reference A shaded, light-absorbing, black material such as velvet may be used to increase the accuracy of the measurement. This reference must have about the same area as the light source or reflective material used for the light reading since the photometer must also measure the apparent luminance of the black reference.

2.3 Test Specimen

The part to be measured shall be cleaned, using an acceptable procedure, to remove any surface contaminants that may contribute to the loss of transmissivity. No special conditioning other than cleaning is required.

2.4 Calibration and Standardization

The photometer should have the same spectral sensitivity as the eye, but since the measurement involves the division of two quantities measured by the photometer, it is not necessary that the photometer be calibrated in absolute luminance units.

2.5 Procedure

1. Place the light source (or white reflective surface) on one side of the transparency such that it can be viewed from the other side. The distance from the light source to the transparency is not critical, but must be greater than thirty (30) centimeters to prevent err neous readings due to light scatter and reflections (see figure 2.1).

2. Position the transparency at the desired angle for measurement.
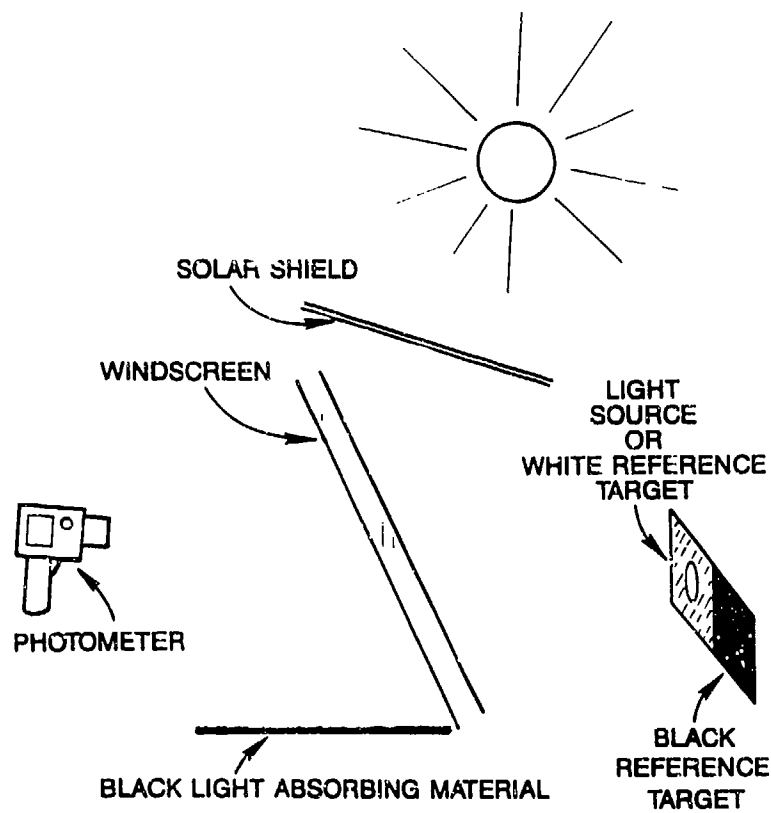
Figure 2.1: Apparatus set-up for the new transmissivity measurement.

3. Position the photometer on the side of the transparency opposite the light source. The distance from the light source to the photometer is also not critical, but should be short enough so that the photometer measurement field easily falls within the emitting area of the light source. The distance from the transparency to the photometer is not critical and may be as small as zero (0) centimeters.

4. Position the black reference next to the light source so it may be viewed through the transparency.

5. Place the light absorbing cloth next to the transparency on the opposite side from the light source as shown in figure 2.1.

6. If the transparency is subject to direct sunlight, use a solar shield to shade the area of the transparency (see figure 2.1).

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7. Using the photometer, measure the luminance of the light source and the black reference. Record these readings as L_s and L_b respectively.

8. Measure the luminance of the light source and the black reference through the transparency. Record these readings as L_{s_t} and L_{b_t} respectively.

   Note: Both the direct measurements and the measurements through the transparency should be made at the same distance and angle from the light source.

9. Calculate the transmissivity of the transparency using the following equation:

$$t = \frac{L_{s_t} - L_{b_t}}{L_s - L_b} \tag{2.1}$$

where t is the transmission coefficient of the transparency, L_s is the luminance of the light source (white surface), L_{s_t} is the luminance of light source measured through the transparency, L_b is the luminance of black reference, and L_{b_t} is the luminance of the black reference measured through the transparency. The second term in the numerator in equation 2.1 removes effects due to light scatter or reflections from the measurement. Similarly, the second term in the denominator removes errors that arise from the black reference pattern not being completely black. See the Appendix for the derivation of this equation.

10. *(Optional)* Convert the transmission coefficient t to percent transmission T by multiplying by 100. In equation form:

$$T = 100t \tag{2.2}$$

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Method Evaluation

3.1 Introduction

The precision and bias of the new method for measuring transmissivity was determined by performing a series of measurements using nine transparent samples at several test locations. These measurements were conducted as part of a Round Robin Test for ASTM Subcommittee F 7.08 on Aerospace Transparent Enclosures and Materials.

The samples included one three-ply laminated sample ($\frac{7}{8}$ inch total thickness), three thick ($\frac{5}{8}$ inch) monolithic samples, and five thin ($\frac{1}{8}$ inch) monolithic samples. The samples ranged from about 15% transmissive to about 90% transmissive, which includes the complete range of transmissivities that would be encountered in aircraft transparencies and helmet visors. There is no reason to expect that thickness of the sample or number of layers would have an effect on the measurement of transmissivity.

Four tests were done on the set of nine samples: 1) measurement using the ASTM D 1003 test method at four laboratories using a total of six devices, 2) repeatability test using one photometer and one operator for twelve trials, 3) reproducibility test using one operator in one laboratory with seven photometers, and 4) reproducibility test using one photometer and six operators at four laboratories. The latter three tests were performed using the procedure described in this report.

The primary statistical parameter used to compare the results of each test was the coefficient of variation (CV). The coefficient of variation is the standard deviation (σ) of the dependent variable divided by the mean of the dependent variable, times 100. It was used because it is a unitless measure of the variance of a population or sample, whereas the standard deviation is an absolute measurement of variance, and interpretation of standard deviation depends upon both the units and magnitude of the dependent variable. The coefficient of variation yields a measure of variance as percent of the mean.

The precision of the measurement was expressed as percent error with a 95% confidence

interval. Assuming a normal distribution, ninety-five percent of the area of the distribution curve will fail within $\pm 1.96\sigma$ of the mean. Conversely, by determining the standard deviation for a certain set of measurements, one can specify the precision of the measurement as 1.96σ with a 95% confidence level. For example, if a certain measurement procedure yields a mean value of 12 units and a standard deviation of 0.25 units, then one can say with a 95% confidence that any measurement made following that procedure will be within $1.96 \times 0.25 = \pm 0.49$ units of the true value. Similarly, one can specify the precision of the measurement as percent of the mean by substituting the coefficient of variation for the standard deviation. In the preceding example, this would yield a 95% confidence interval of $1.96 \times \frac{0.25}{12} \times 100 = 4.1\%$.

3.2   Reproducibility of ASTM D 1003

Method

To evaluate the precision of the new test procedure it was desirable to compare it to the precision of the already accepted D 1003 method. Since no data were available on the precision of D 1003, it was necessary to gather data using both test methods. Nine samples were measured using the D 1003 method at four laboratories on six devices, yielding 54 measurements. The standard deviation, variance, coefficient of variation, and 95% confidence interval were calculated for the six measurements made on each sample.

Results

The results of the reproducibility test of the D 1003 procedure are shown in table 3.1. The mean standard deviation was 0.45, the mean variance was 0.214, and the mean coefficient of variation was 0.97%, resulting in a 95% confidence interval of $\pm 1.90\%$ of the transmissivity reading. It should be noted that the coefficient of variation was not uniform with respect to transmissivity but tended to be higher for lower transmissivities. This was because the device used for D 1003 had a fixed light sensing range. Thus for low transmissivities the least count of the device represented a larger percent change of the reading than at higher transmissivities.

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Table 3.1: Results of the reproducibility test of ASTM D 1003.

Organization	Sample									Mean
	1	2	3	4	5	6	7	8	9	
AAMRL-1	91.7	87.1	87.6	90.2	47.3	70.2	34.2	27.0	14.6	61.10
AAMRL-2	91.2	86.3	85.9	88.6	46.5	69.1	33.4	26.5	14.4	60.21
Swedlow-1	90.6	86.1	85.4	88.2	46.2	68.8	33.0	25.8	13.6	59.74
Swedlow-2	91.0	86.0	86.0	88.6	46.4	69.2	33.4	26.4	14.0	60.11
Sierracin	90.7	86.4	85.8	88.6	46.8	69.3	33.8	26.7	14.5	60.29
Dow	91.6	87.0	86.2	88.9	46.5	69.1	33.6	26.5	14.3	60.41
Mean	91.13	86.48	86.15	88.85	46.62	69.28	33.57	26.48	14.23	60.31
σ	0.41	0.42	0.69	0.64	0.35	0.44	0.37	0.36	0.34	0.45
σ^2	0.168	0.176	0.476	0.410	0.123	0.194	0.137	0.130	0.116	0.214
CV	0.46	0.49	0.80	0.72	0.76	0.63	1.11	1.37	2.39	0.97
Max	91.7	87.1	87.6	90.2	47.3	70.2	34.2	27.0	14.6	61.1
Min	90.6	86.0	85.4	88.2	46.2	68.8	33.0	25.8	13.6	59.7
Range	1.1	1.1	2.2	2.0	1.1	1.4	1.2	1.2	1.0	1.37

3.3 Repeatability of the New Procedure

Method

All nine samples were measured following the new procedure at one laboratory (AAMRL) using a single photometer and a single operator for twelve trials, yielding 108 measurements. The standard deviation, variance, and coefficient of variation were calculated.

Results

The results of the repeatability test are shown in table 3.2. The mean standard deviation was 0.10, the mean variance (σ_c^2) was 0.012, and the mean coefficient of variation was 0.18. The coefficient of variation was fairly uniform independent of the transmissivity of the sample.

3.4 Reproducibility Using Different Photometers

Method

All nine samples were measured following the new procedure using the same operator but seven different photometers at a single laboratory, yielding 63 measurements. The standard

Table 3.2: Results of the transmissivity repeatability test with one operator and one photometer.

Trial	Sample									
	1	2	3	4	5	6	7	8	9	
1	39.70	84.62	83.67	87.33	47.00	68.56	33.44	25.77	14.60	59.41
2	89.97	84.62	83.67	87.33	47.00	68.67	33.67	25.73	14.60	59.47
3	89.97	84.67	83.67	87.33	47.00	68.44	33.55	25.77	14.60	59.44
4	89.90	84.56	83.56	87.54	47.14	68.69	33.67	25.77	14.58	59.49
5	89.83	84.46	83.78	87.50	46.96	68.58	33.45	25.84	14.58	59.44
6	89.90	84.51	83.84	87.54	47.14	68.58	33.45	25.76	14.58	59.48
7	89.86	84.46	83.78	87.16	46.96	68.58	33.45	25.78	14.63	59.41
8	89.93	84.56	83.89	87.58	47.14	68.69	33.56	25.77	14.56	59.52
9	89.97	84.33	83.67	87.33	46.82	68.69	33.56	25.84	14.65	59.43
10	89.93	84.56	83.89	87.58	46.98	68.79	33.67	25.84	14.56	59.53
11	89.46	84.35	84.01	87.37	47.10	68.60	33.33	25.84	14.57	59.40
12	89.86	84.18	83.84	87.25	47.14	68.69	33.67	25.86	14.58	59.45
Mean	89.86	84.49	83.77	87.40	47.03	68.63	33.54	25.80	14.59	59.46
σ_c	0.14	0.14	0.12	0.13	0.10	0.09	0.11	0.04	0.03	0.10
$\sigma_c{}^2$	0.020	0.020	0.014	0.017	0.010	0.008	0.012	0.002	0.001	0.012
CV	0.16	0.16	0.15	0.15	0.21	0.13	0.33	0.16	0.18	0.18
Max	89.97	84.67	84.01	87.58	47.14	68.79	33.67	25.86	14.65	59.59
Min	89.46	84.18	83.56	87.16	46.82	68.44	33.33	25.73	14.56	59.25
Range	0.51	0.49	0.45	0.42	0.32	0.35	0.34	0.13	0.09	0.34

Table 3.3: Results of the transmissivity reproducibility test using different photometers.

Photometer	Sample									Mean
	1	2	3	4	5	6	7	8	9	
# 305 ($\frac{1}{3}°$)	89.43	84.38	84.09	87.33	47.33	68.66	33.80	25.80	14.66	59.50
# 331 ($\frac{1}{3}°$)	89.02	84.17	83.88	86.92	46.53	67.78	33.46	25.67	14.51	59.10
# 035 (1°)	89.90	84.49	83.86	86.94	46.51	68.25	33.01	25.94	14.71	59.20
# 445 (1°)	89.55	84.48	83.95	87.41	47.04	68.63	33.75	25.81	14.59	59.47
# 144 (1°)	89.76	84.42	83.82	87.45	47.01	68.64	33.44	25.92	14.70	59.46
Prit 1980A	89.01	84.94	84.27	87.41	47.04	68.55	33.64	25.78	14.51	59.46
Prit 1980	89.14	85.06	84.67	87.49	46.98	68.94	33.73	25.80	14.31	59.57
Mean	89.40	84.56	84.08	87.28	46.92	68.49	33.55	25.82	14.57	59.41
σ_{pc}	0.33	0.30	0.28	0.23	0.27	0.35	0.25	0.08	0.13	0.26
$\sigma_p^2 + \sigma_c^2$	0.109	0.090	0.078	0.053	0.073	0.113	0.063	0.006	0.017	0.068
CV	0.37	0.35	0.34	0.26	0.59	0.51	0.76	0.33	0.90	0.49
Max	89.90	84.94	84.27	87.45	47.33	68.66	33.80	25.94	14.71	59.7
Min	89.01	84.17	83.82	86.92	46.51	67.78	33.01	25.67	14.51	59.0
Range	0.89	0.77	0.45	0.53	0.82	0.88	0.79	0.27	0.20	0.62

deviation, variance, and coefficient of variation were calculated.

Results

The results of the reproducibility test using different photometers is shown in table 3.3. The mean standard deviation was 0.26, the mean variance was 0.068, and the mean coefficient of variance was 0.49. The estimate of the variance σ_p^2 was $(\sigma_p^2 + \sigma_c^2) - \sigma_c^2 = 0.068 - 0.012 = 0.056$.

3.5 Reproducibility Using Different Operators at Different Laboratories

Method

All nine samples were measured with this procedure at four laboratories with a total of six operators using a single photometer, yielding 54 measurements. The standard deviation, variance, and coefficient of variation were calculated.

Table 3.4: Results of the transmissivity reproducibility test with different operators in different laboratories.

Organization	Sample									Mean
	1	2	3	4	5	6	7	8	9	
AAMRL-1	90.2	85.1	84.5	87.5	47.2	68.6	33.5	25.9	14.6	59.68
AAMRL-2	89.5	84.8	84.5	87.2	46.9	68.8	33.9	25.8	14.5	59.54
Swedlow	90.3	85.4	84.1	87.4	46.9	68.6	33.7	26.2	14.6	59.69
Sierracin	90.0	84.7	83.7	86.5	47.0	68.3	33.6	25.8	14.6	59.36
Dow-1	89.6	84.9	84.3	86.3	47.1	68.4	33.6	25.9	14.6	59.41
Dow-2	90.1	84.9	84.3	86.7	47.2	68.9	33.6	25.9	14.6	59.58
Mean	89.95	84.97	84.23	86.93	47.05	68.60	33.65	25.92	14.58	59.54
σ_{oc}	0.30	0.23	0.27	0.46	0.13	0.21	0.13	0.13	0.04	0.21
$\sigma_o^2 + \sigma_c^2$	0.090	0.053	0.073	0.212	0.0167	0.044	0.017	0.017	0.002	0.058
CV	0.33	0.27	0.33	0.53	0.27	0.30	0.37	0.52	0.26	0.35
Max	90.3	85.4	84.5	87.5	47.2	68.9	33.9	26.2	14.6	59.8
Min	89.5	84.7	83.7	86.3	46.9	68.3	33.5	25.8	14.5	59.2
Range	0.8	0.7	0.8	1.2	0.3	0.6	0.4	0.4	0.1	0.59

Note: Samples 1 to 4 had high haze readings; samples 5 to 9 had low or zero haze readings.

Results

The results of the Round Robin reproducibility test are shown in table 3.4. The mean standard deviation was 0.21, the mean variance was 0.058, and the mean coefficient of variation was 0.35%. The estimate of the variance σ_o^2 was $(\sigma_o^2 + \sigma_c^2) - \sigma_c^2 = 0.058 - 0.012 = 0.046$.

3.6 Precision of the New Method

Considering a typical application of the new method to involve different operators in different laboratories using different photometers, the confidence interval may be estimated from the acquired data. The variance of the transmissivity measurement, σ^2, may be modeled as:

$$\sigma^2 = \sigma_o^2 + \sigma_p^2 + \sigma_c^2 \tag{3.1}$$

where σ_o^2 is the variance of the operator, σ_p^2 is the variance of the photometer, and σ_c^2 is the variance of the repeatability error. It is assumed there is no operator-photometer

interaction. Substituting the appropriate values into equation 3.1 yields:

$$\sigma^2 = 0.115 \tag{3.2}$$

$$\sigma = 0.34 \tag{3.3}$$

The coefficient of variation is then:

$$CV = \frac{\sigma}{\bar{x}} \times 100\% = 0.57\% \tag{3.4}$$

where $\bar{x}$ is the mean transmissivity of the samples (0.595). The corresponding 95% confidence interval is then:

$$\pm\, 1.96 \times CV = \pm 1.12\% \tag{3.5}$$

Conclusions

4.1 Discussion of Results

The results of the above evaluation show that the new method of measuring transmissivity is slightly more precise than the existing method ASTM D 1003. The coefficient of variation for the new method is 0.57%, versus 0.97% for ASTM D 1003. The 95% confidence interval of the new method is 1.12%, versus 1.90% for ASTM D 1003.

4.2 Bias

This test method has no known inherent bias. However, it is likely one will obtain slightly different results using this method than the ASTM D 1003 test method. When light is incident on a nominally transparent part the transmitted light is composed of both scattered and unscattered components. The scattered light is measured as haze using ASTM D 1003. The unscattered light is the only useful transmitted light for image formation and visibility. The present test method measures almost exclusively the unscattered transmitted light whereas the ASTM D 1003 method measures a combination of both the scattered and unscattered transmitted light. Therefore the ASTM D 1003 test method will usually result in higher transmissivity values than the new test method for parts that exhibit measurable haze.

The degree of difference depends on the amount of haze in the transparent material. Four of the nine samples tested had haze readings in the region of 1 - 2%. These samples had transmissivity values of 84% to 90% using the present method, but registered a mean of 1.6% higher using the ASTM D 1003 test method. The other five samples had very low haze readings (less than 0.1%) and showed a random relationship with the ASTM D 1003 method.

4.3 Comments on Application

The present test method is the appropriate one to use if the transparency under test is to be used for visual or sensor image transmission such as an aircraft windscreen or sensor protective cover. ASTM D 1003 may be used to determine the haze and transmissivity of thin, flat, unscratched samples. If the sample is to be used for image transmission, the haze effects should be subtracted from the transmissivity reading.

The new method for measuring transmissivity was specifically developed for application to aircraft transparencies. It overcomes the limitations of applying D 1003 to aircraft transparencies, such as the requirement of critical alignment of equipment and the restrictions on large, thick, and curved parts and making measurements other than perpendicular to the test sample.

Appendix A: Derivation of the Transmissivity Equation

This appendix provides a brief derivation of quation 2.1, which is used to calculate transmissivity. It is necessary to devise a means to remove the effects of light scatter and reflections from the measurement of transmissivity. It is assumed that the unwanted light, S, is sufficiently uniform that it does not change appreciably during the time of the test nor does it vary over the area of the transparency required to measure both the light source target and the black reference target.

The light level measured through the transparency will be reduced by a factor equal to the transmissivity, t, and will be enhanced by a term equal to the scattered/reflected light, S. In equation form:

$$L_{s_t} = t \times L_s + S \text{ for measuring the light source and}$$

$$L_{b_t} = t \times L_b + S \text{ for measuring the black reference.}$$

where t is the transmission coefficient of the transparency, L_s is the luminance of the light source (white surface), L_{s_t} is the luminance of light source measured through the transparency, L_b is the luminance of black reference, L_{b_t} is the luminance of the black reference measured through the transparency, and S is the unknown scattered/reflected light.

Solving these two equations for S and setting them equal yields:

$$S = L_{s_t} - t \times L_s = L_{b_t} - t \times L_b$$

Solving for t yields the desired equation:

$$t = \frac{L_{s_t} - L_{b_t}}{L_s - L_b}$$

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